Optical Instrument Thermal Control on the Large Ultraviolet/Optical/Infrared Surveyor

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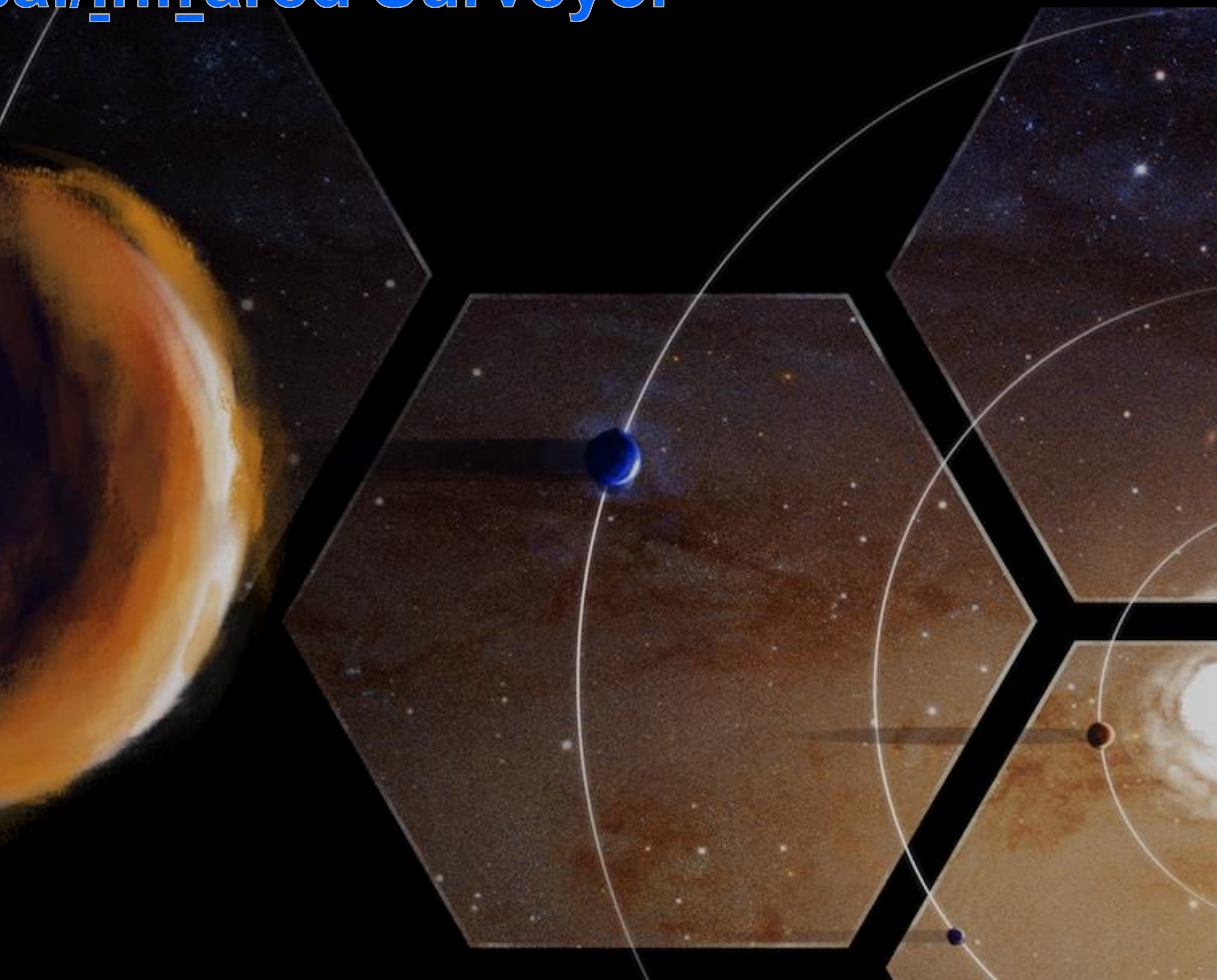

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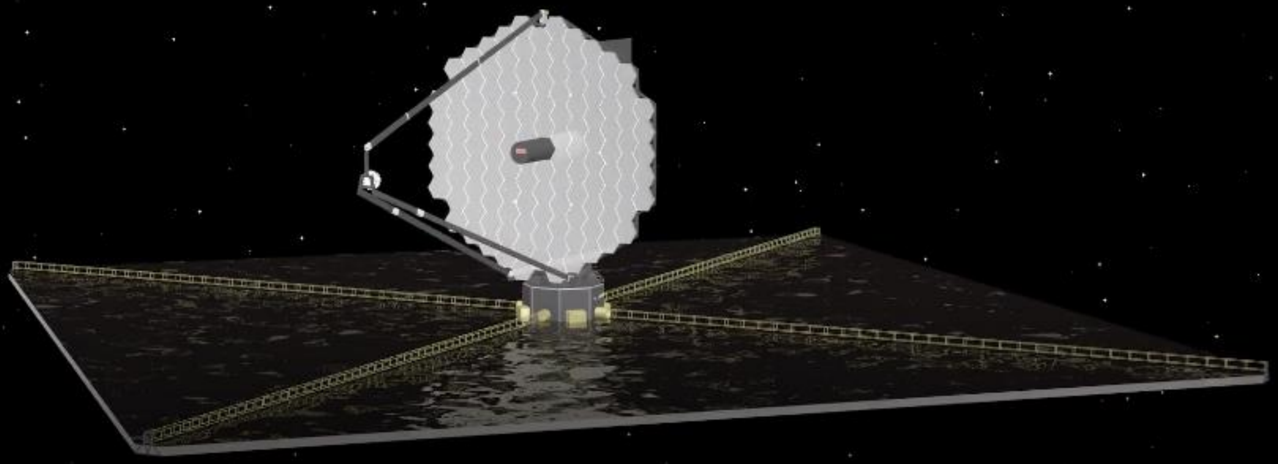
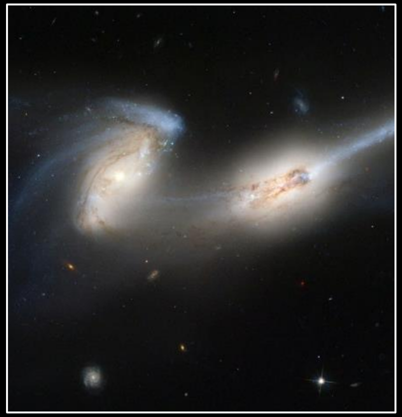
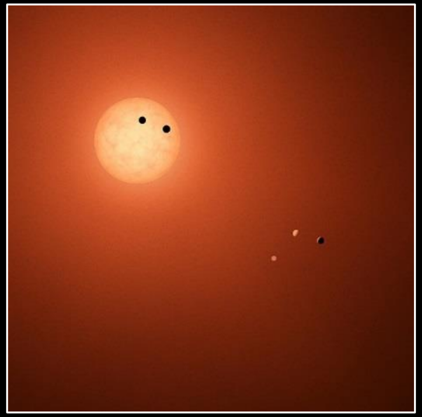
What is LUVOIR?

- The Large Ultraviolet/ Optical/ Infrared Surveyor (LUVOIR) is a multi-wavelength general-purpose space observatory
    - One of four concept studies for the 2020 Decadal Survey in Astronomy / Astrophysics
- LUVOIR enables broad range of astrophysics to be performed:
    - Galaxy and planet evolution
    - Star and planet formation
    - Exoplanet atmospheric and surface composition (assessing habitability, biosignatures) to answer question “are we alone?”
- LUVOIR operates at Sun-Earth Lagrange Point 2 orbit



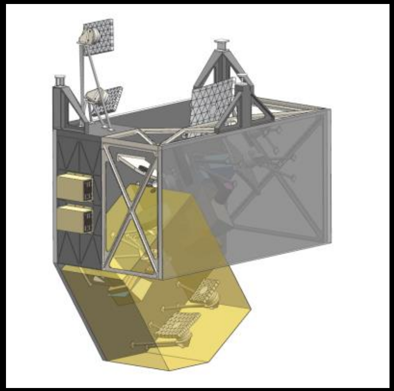




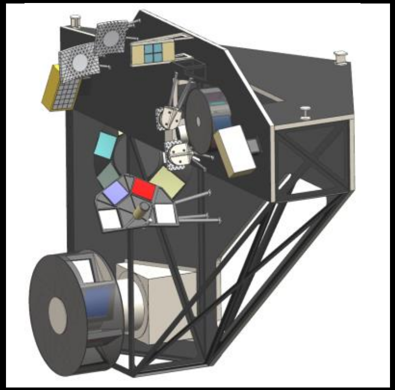
LUVOIR's Instruments

- **Extreme Coronagraph for Living Planetary Systems (ECLIPS):** Coronagraph with imaging, integral-field spectroscopy, and point-source spectroscopy capabilities
  - 200 nm – 2.0 µm bandpass; Ultraviolet (UV), Visible (VIS), Near-Infrared (NIR) channels
- **High Definition Imager (HDI):** wide field-of-view camera with Imaging, GRISM Spectroscopy, Fine Guiding, Phase Retrieval, and Astrometric capabilities
  - 200 nm – 2.5 µm bandpass, UV/VIS, Near-IR channels
- **LUVOIR UV Multi-Object Spectrograph (LUMOS):** multi-object spectroscopy and imaging
  - 100 nm – 1.0 µm bandpass; Far-UV, Near-UV, VIS channels
- **Pollux:** spectropolarimetry and pure spectroscopy capabilities (Centre National d' Études Spatiales)
  - 100 nm – 390 nm bandpass; Far-UV, Mid-UV, Near-UV channels

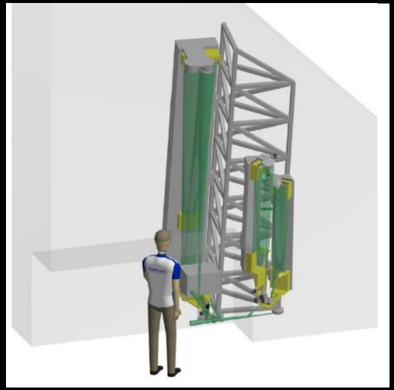
ECLIPS



HDI

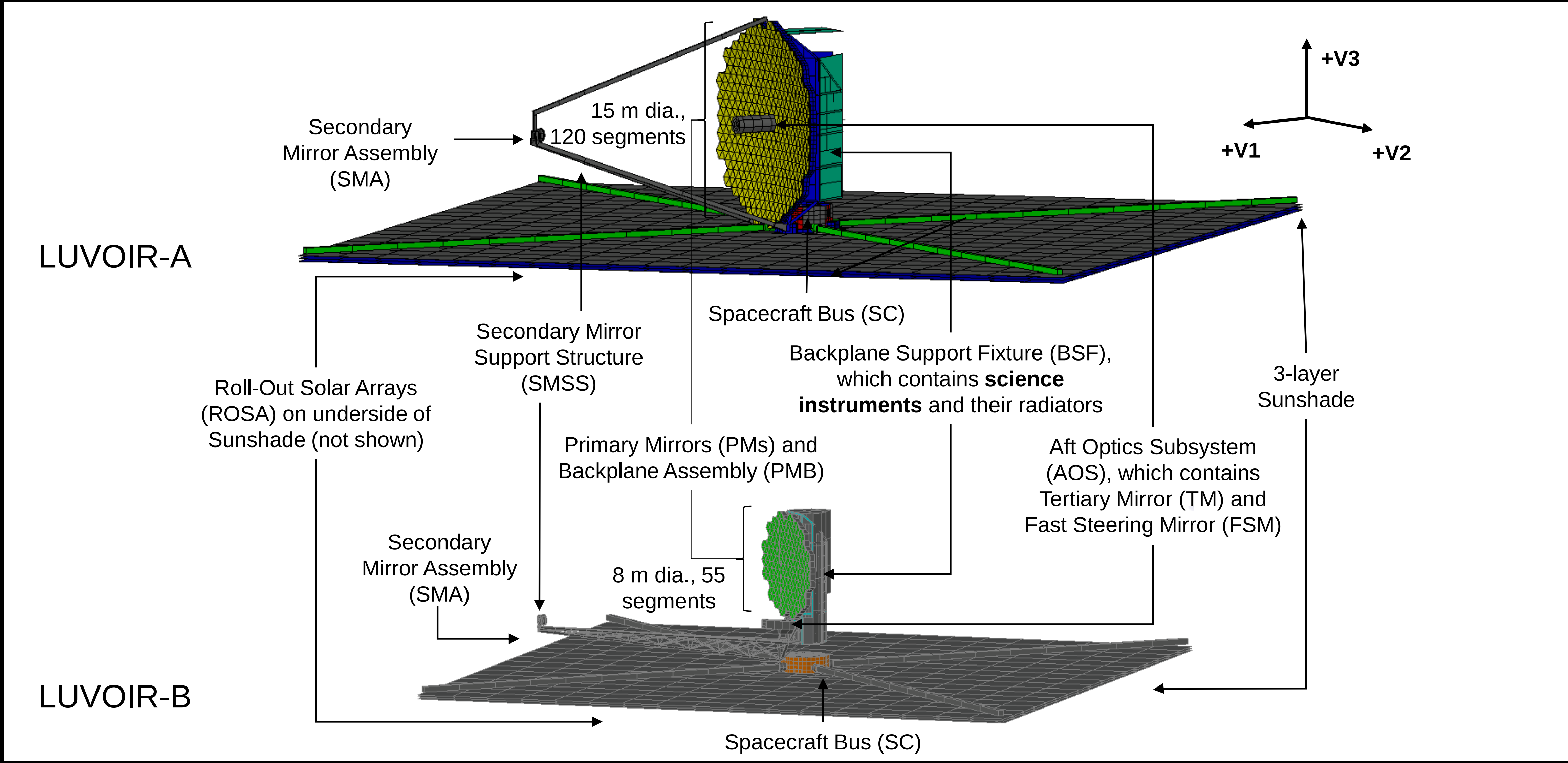


LUMOS

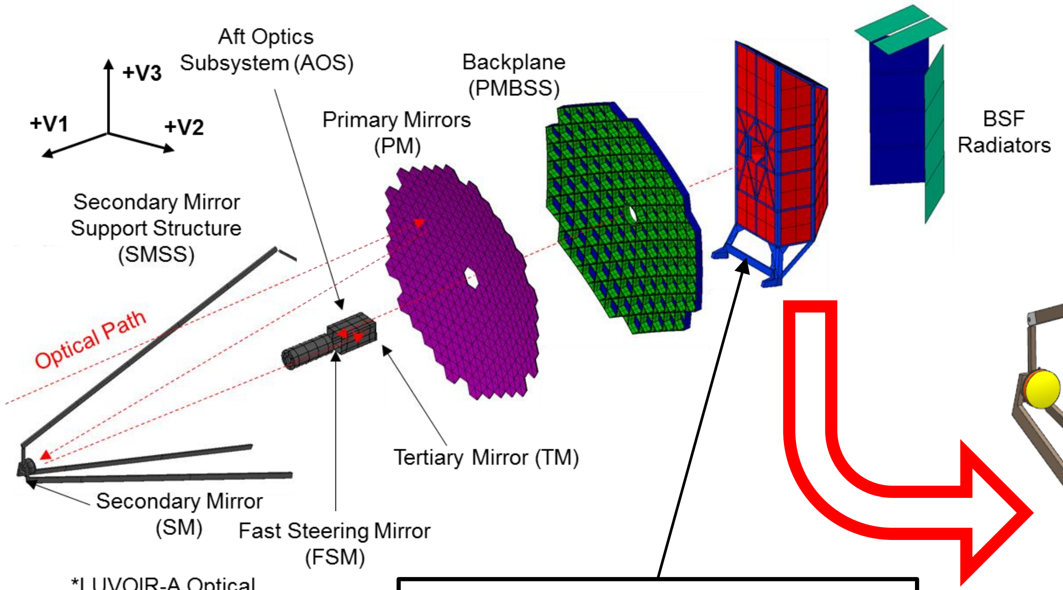


Pollux

Two LUVOIR Concepts

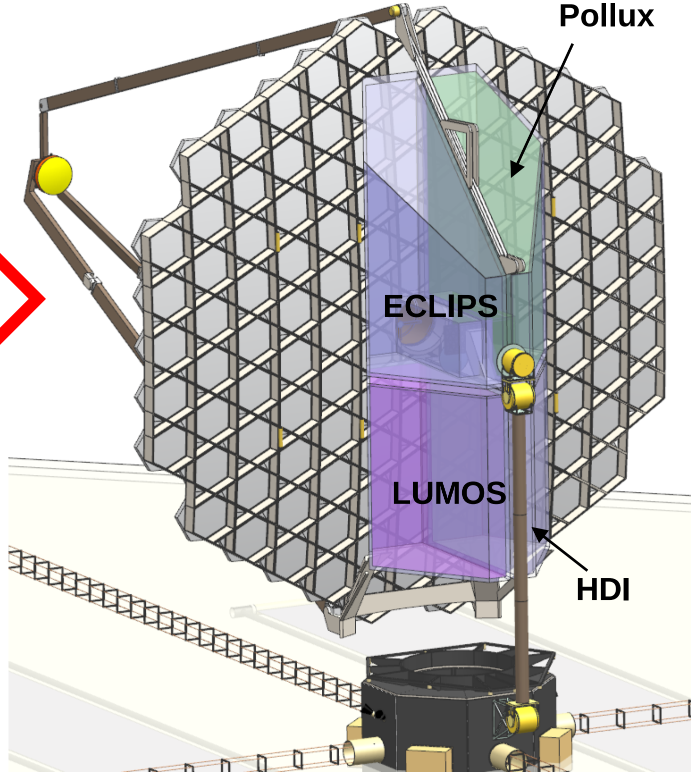


Instrument Layout

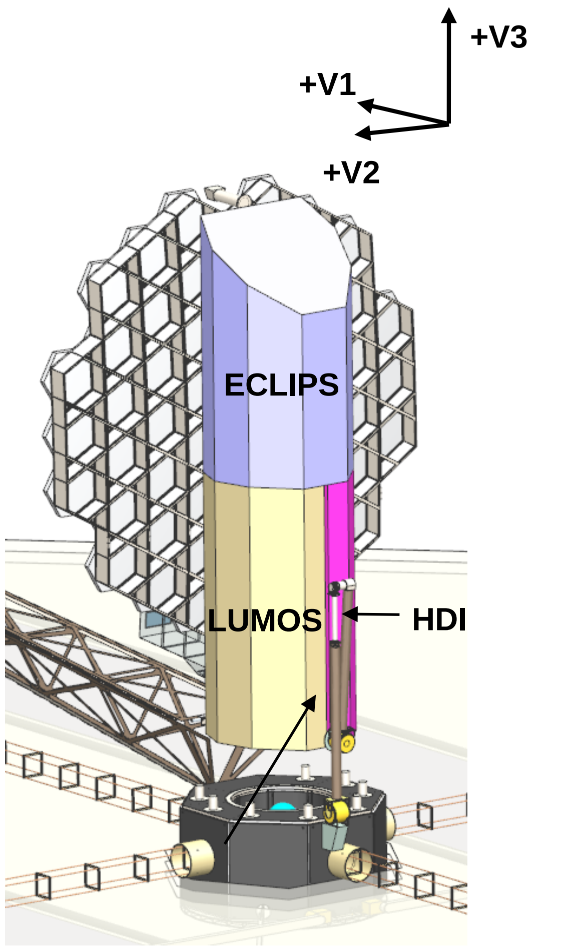


*LUVOIR-A Optical Telescope Assembly shown, but LUVOIR-B assembly is very similar

BSF (Backplane Support Fixture)
- Composite truss structure: Vapor Deposited Aluminum (VDA) outer-layer MLI
- Composite Shear Panels: VDA-outer-layer MLI on external-facing surfaces, Black Kapton (BK) Single-Layer Insulation (SLI) internal-facing surfaces
- Foil heaters covering all surfaces



LUVOIR-A



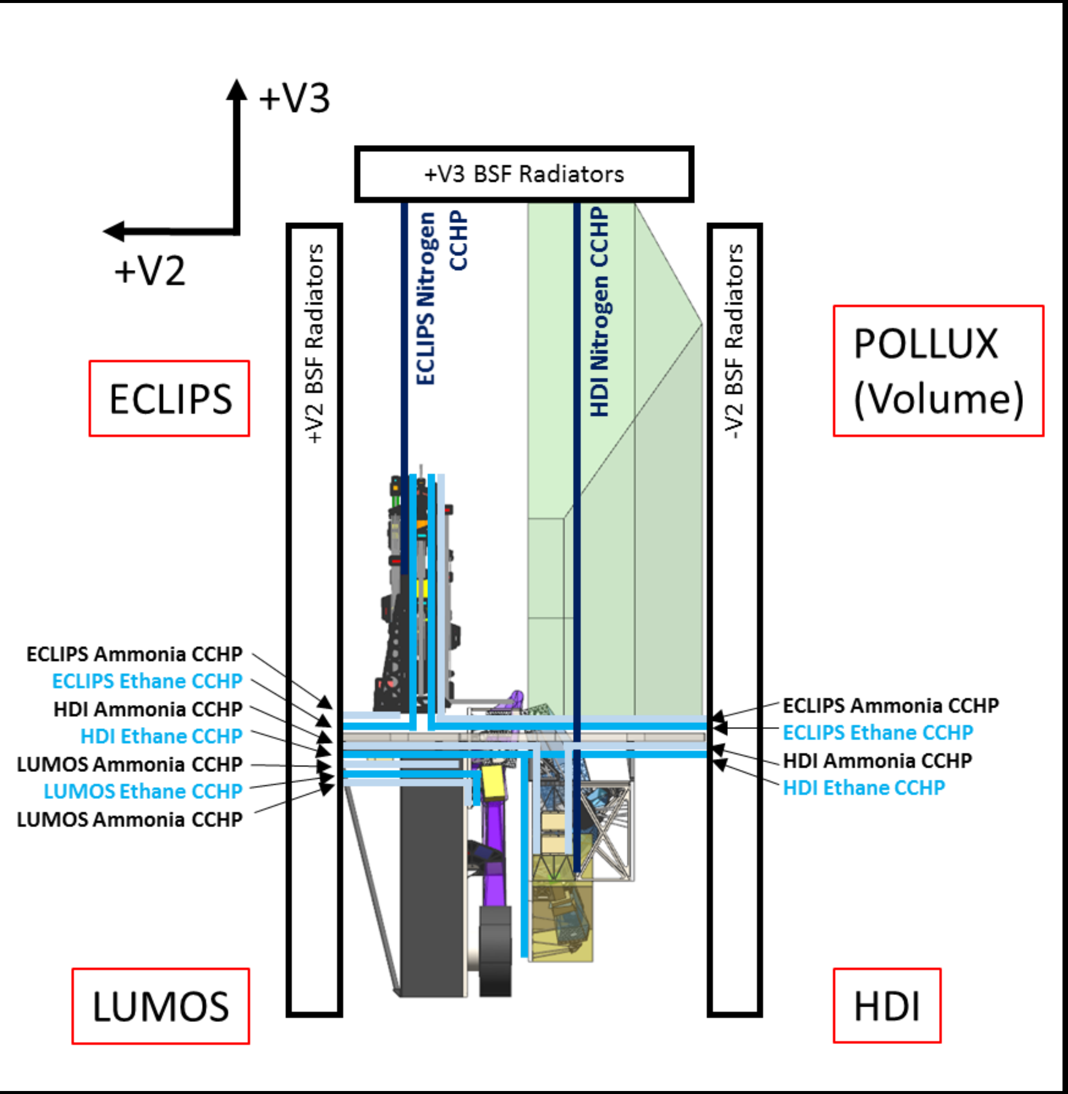
LUVOIR-B

Instrument Thermal Design Requirements

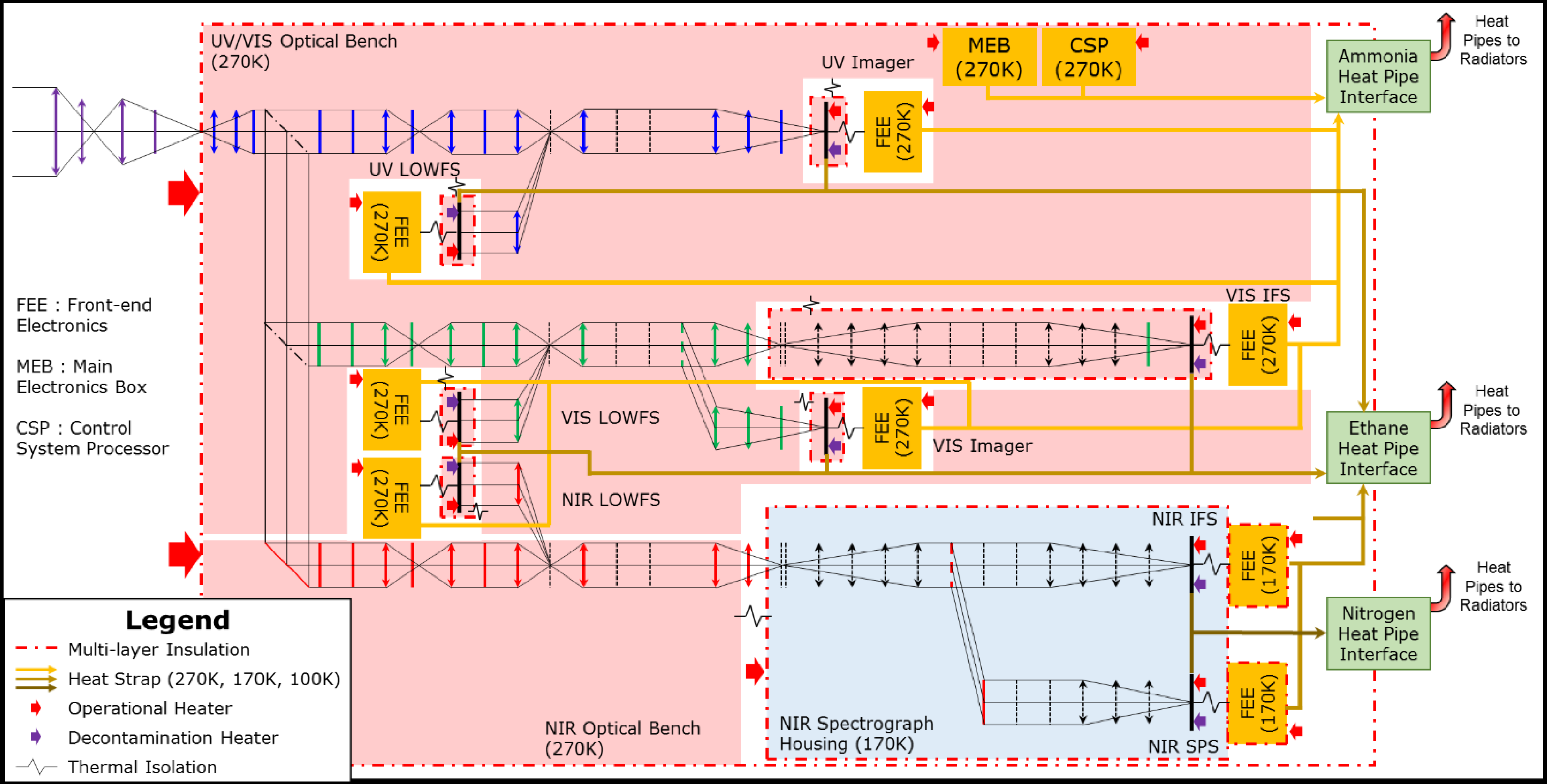
	ECLIPS	HDI	LUMOS
270 K - 280 K Zone Components	Optical Benches, UV/VIS Front End Electronics (FEE); Main Electronics Box (MEB), Control System Processor (CSP) (all 270 K)	UV/VIS Optical Bench and components; MEB (all 270 K)	Optical Bench; FUV: Multi-Object Spectrograph (MOS), Imager, FEEs; MEB, Microshutter Array (MSA), LUMOS Microshutter Control Electronics (LMCE), High-Voltage Power Source (HVPS) (all 280 K)
270 K Zone Temperature Stability	± 0.5 K benches and FEEs; ±1 K electronics	± 0.5 K benches; no requirement for electronics	± 3 K FUV and benches; no requirement for electronics
170 K Zone Components	NIR Low-Order Wavefront Sensor (LOWFS); VIS: Imager, LOWFS, Integral Field Spectrograph (IFS); UV: Imager, LOWFS; all NIR FEES	NIR: FEE, Filter Wheel (FW), and mirrors; UV/VIS: Focal Plane Assembly (FPA) and FEE	NUV MOS
170 K Zone Temperature Stability	± 0.5 K	± 0.005 K UV/VIS FPA, ± 0.5 K all others	± 0.1 K
100 K Zone Components	NIR IFS, NIR Single Planet Spectrograph (SPS)	NIR FPA	--
100 K Zone Temperature Stability	± 0.5 K	± 0.01 K	--

Instrument Thermal Design Overview

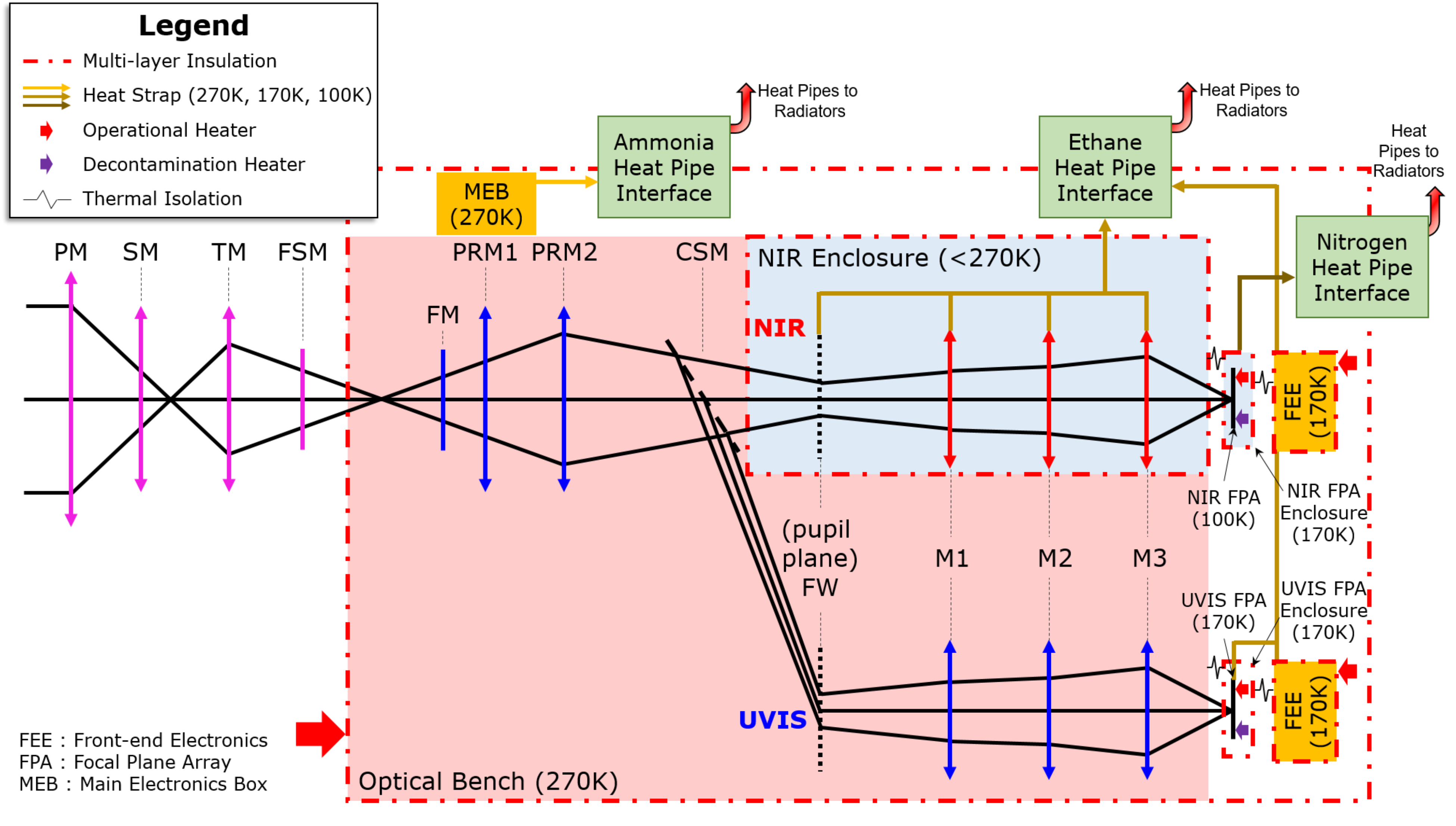
- Optical benches are actively heated
  - Instruments reside in a warm sink environment provided by the actively-heated BSF panels
- Components reject their heat with Oxygen-Free High Conductivity (OFHC) copper heat straps, which interface with Constant Conductance Heat Pipes (CCHPs) to transport heat to the radiators
  - 100 K components use Nitrogen CCHPs to 80 K radiator on +V3 side of BSF
  - 170 K components use Ethane CCHPs to 150 K radiator on ±V2 sides of BSF
  - 270 K components use Ammonia CCHPs to 250 K radiator on ±V2 sides of BSF
  - All heat pipes arrayed in V2/V3 plane for ease of testing
- Blanket tent around each instrument
- Detectors are cold-biased and actively heated
- Decontamination heaters for each detector



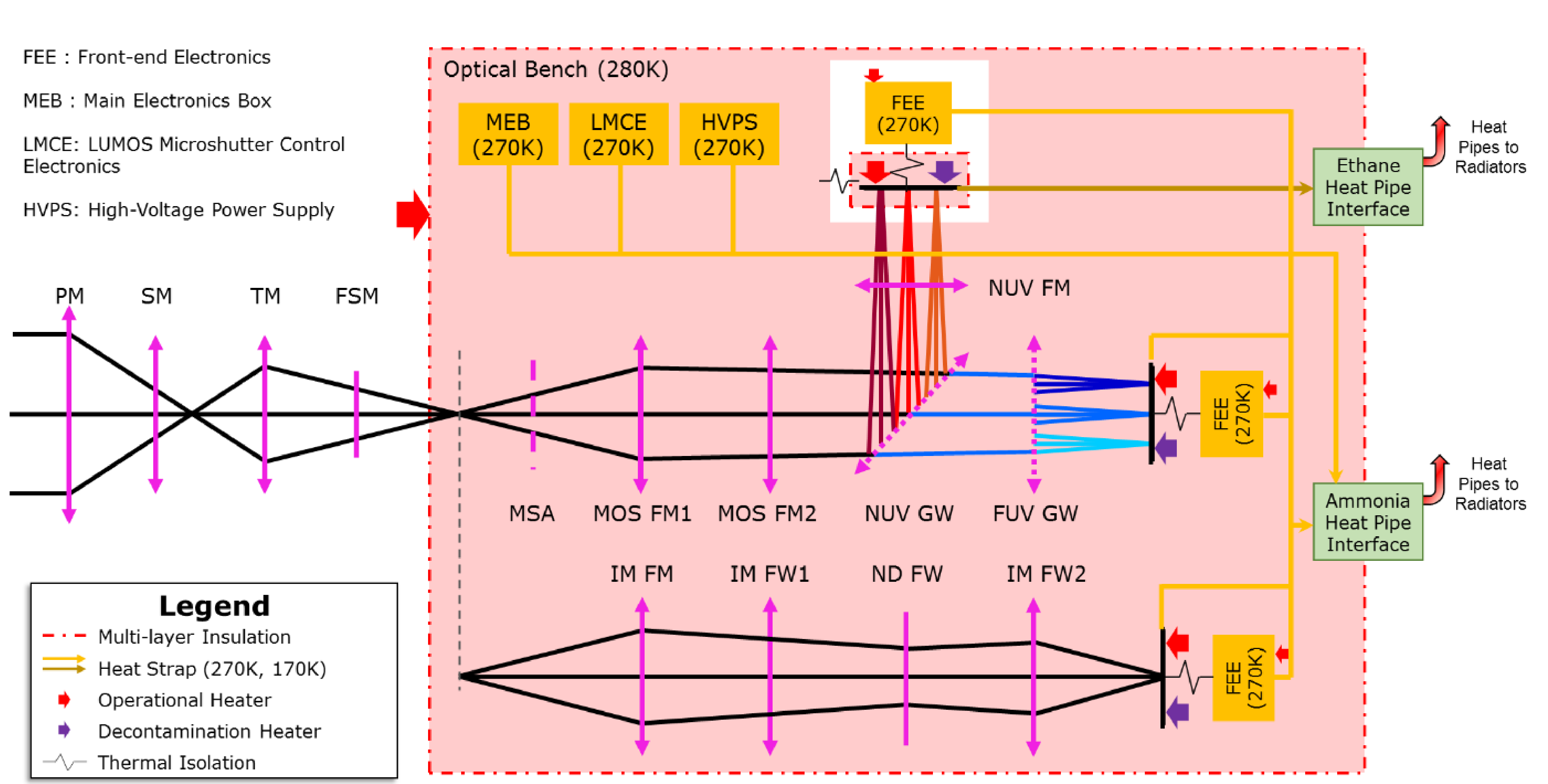
ECLIPS Detailed Thermal Block Diagram



HDI Detailed Thermal Block Diagram



LUMOS Detailed Thermal Block Diagram



Preliminary Thermal Analysis: Heater Power

	ECLIPS-A	ECLIPS-B	LUMOS-A	LUMOS-B	HDI-A	HDI-B
Operational Heater Power for Electronics Boxes and Optical Components (W)	23.5	23.5	88.2	77.5	29.4	8.2
Operational Heater Power for Optical Benches (W)	28.4	28.4	109.0	77.0	49.3	28.2
Decontamination Heater Power (W)	6.4	6.4	76.4	61.8	56.7	22.9
Survival Heater Power (W)	58.4	58.4	331.7	221.7	112.1	44.4

- 40% uncertainty margin added for heater powers
- Relatively small optical bench heater powers considering their size, due to warm sink provided by actively heated BSF
  - LUMOS has higher heater power due to setpoint at 280 K for contamination avoidance
- For electronics boxes and optical components: heater powers estimated based on desired operational temps and to compensate for heat lost to radiators if not dissipating at max value

Preliminary Thermal Analysis: Heat to Radiator and Radiator Area

	ECLIPS-A	ECLIPS-B	LUMOS-A	LUMOS-B	HDI-A	HDI-B
Total Heat to 80 K Radiator (W)	0.3	0.3	--	--	3.2	3.1
Total Heat to 150 K Radiator (W)	14.0	14.0	36.3	11.9	68.0	48.0
Total Heat to 250 K Radiator (W)	407.4	407.4	329.3	238.9	99.9	96.0
Total 80 K Instrument Radiator Area (m^2)	0.3	0.2	--	--	4.1	2.2
Total 150 K Instrument Radiator Area (m^2)	0.8	1.1	2.1	0.9	4.0	3.7
Total 250 K Instrument Radiator Area (m^2)	2.1	2.1	1.7	1.2	0.5	0.5

- Heat dissipation margin 50% for 170 K components, 100% for 100 K components
- BSF contains enough surface area in both concepts for fixed radiators
  - No deployables necessary

Conclusions and Recommendations

- Thermal design has been presented for instruments in both LUVOIR observatory concepts
  - Each instrument is enclosed within warm BSF
  - Three general thermal zones: 100 K, 170 K, 270-280 K
  - Series of heaters on each instrument drive components and optical benches to operational temperatures
  - Each thermal zone has its won dedicated transport heat pipes to corresponding radiators
  - LUVOIR-A requires significantly more heater power than LUVOIR-B, but power does not just scale with size of observatory
- For future development of LUVOIR:
  - Heat transport system design needs to be matured; more detailed quantification of parasitic heat leaks into heat pipes required
  - Verification of thermal design is critical to LUVOIR’s success: extensive thermal analysis and test planning required to ensure instruments are being tested in flight-like condition, including considerations of heat pipe levelness and cross-talk between instruments and BSF

List of Acronyms (1)

AOS	Aft Optics System	**FUV**	Far Ultraviolet
BK	Black Kapton coating	**FW**	Filter Wheel
BSF	Backplane Support Frame	**GSFC**	NASA Goddard Space Flight Center
CCHP	Constant Conductance Heat Pipe	**GW**	Grating Wheel
CSM	Channel Select Mechanism	**HDI**	High Definition Imager
CTE	Coefficient of Thermal Expansion	**HVPS**	High-Voltage Power Source
ΔT	Change in temperature	**IFS**	Integral Field Spectrograph
DM	Deformable Mirror	**IM**	Imager Mirror
ECLIPS	Extreme Coronagraph for Living Planetary Systems	**IR**	Infrared
FC	Field Corrector	**IS**	Image Surface
FEE	Front-End Electronics	**LMCE**	LUMOS Microshutter Control Electronics
FM	Fold Mirror	**LOWFS**	Low-Order Wavefront Sensor
FPA	Focal Plane Assembly	**LUMOS**	LUVOIR Ultraviolet Multi-object Spectrograph
FPM	Focal Plane Mask	**LUVOIR**	the Large Ultraviolet/Optical/Infrared Surveyor
FSM	Fast Steering Mirror	**K**	Kelvin

List of Acronyms (2)

m	Meter	**PMBSS**	Primary Mirror Backplane Support Structure
MEB	Main Electronics Box	**PR, PRM**	
MLI	Multi-Layer Insulation	**RM**	Relay Mirror
MOS	Multi-object Spectrograph	**ROSA**	Roll-Out Solar Array
MSA	Micro-Shutter Array	**SC**	Spacecraft
NASA	National Aeronautics and Space Administration	**SLI**	Single-Layer Insulation
ND	Neutral Density	**SM**	Secondary Mirror
NIR	Near-Infrared	**SMSS**	Secondary Mirror Support Structure
NUV	Near-Ultraviolet	**SPS**	Single Planet Spectrograph
OAP	Off-Axis Parabola	**TM**	Tertiary Mirror
OFHC	Oxygen-Free High Conductivity copper	**ULE**	Ultra Low Expansion glass
OTA	Optical Telescope Assembly	**UV**	Ultraviolet
PAS	Payload Articulation System	**UVIS**	Ultraviolet /Visible
PID	Proportional-Integral-Derivative Control	**VDA**	Vapor-Deposited Aluminum coating
PDU	Power Distribution Unit	**VIS**	Visible light
PM		**W**	Watt(s)